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(54) **MINIATURE WIDEBAND RF CHOKE**

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H03H 7/01 (2006.01)
H01H 5/02 (2006.01)

(52) **U.S. Cl.** **333/181**; 333/185; 336/200

(58) **Field of Classification Search** 333/12, 333/181, 185; 336/200, 232, 205, 244
See application file for complete search history.

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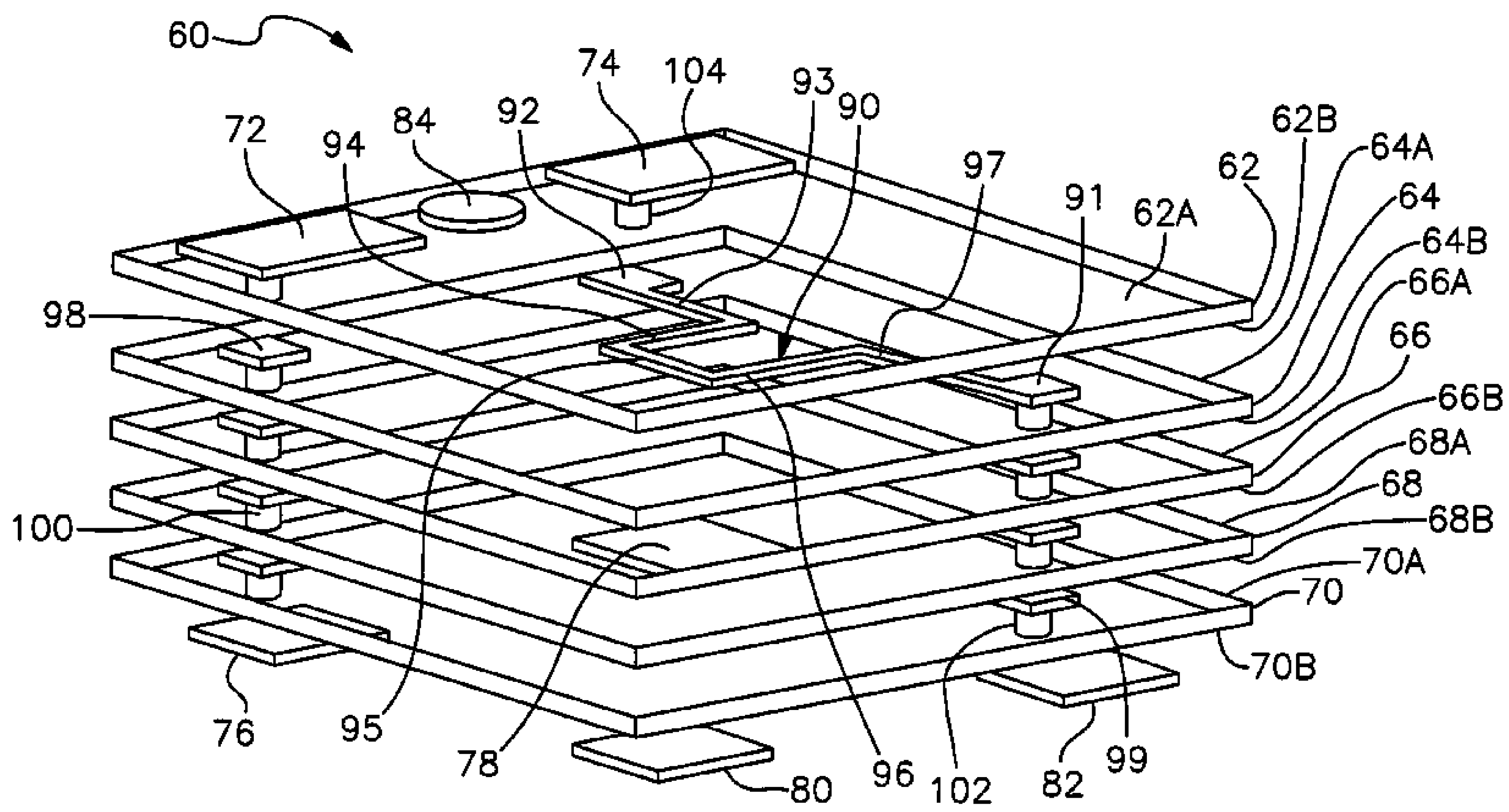
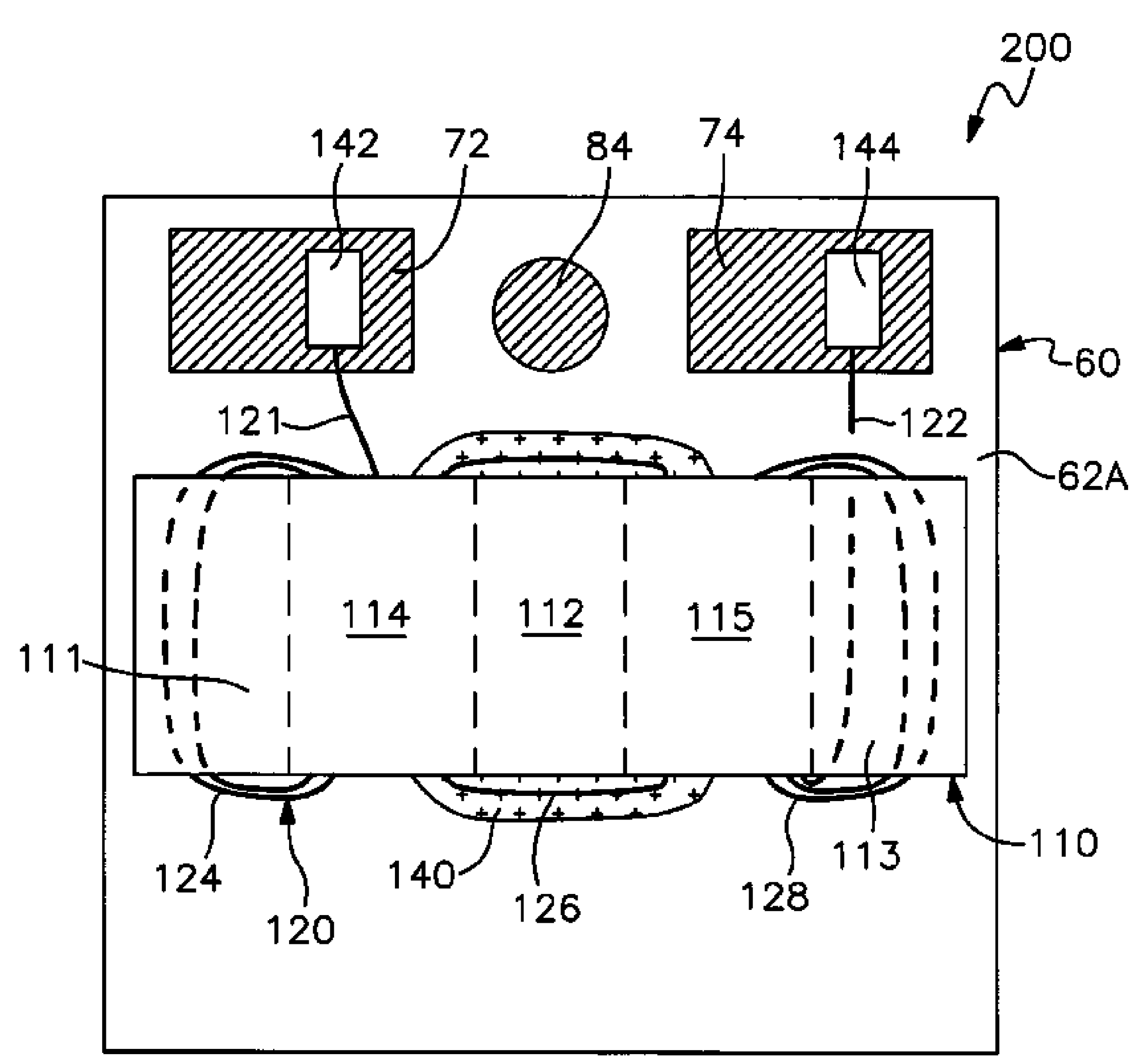
(57) **ABSTRACT**

A miniature wideband RF choke has a low temperature co-fired ceramic substrate with a top surface and a bottom surface. A first inductor is located within the substrate. Terminals are located on the top and bottom surfaces. A second inductor is located on the top surface. The second inductor has a core wound with a wire. Vias extend through the substrate connecting the terminals to the inductors.

22 Claims, 7 Drawing Sheets





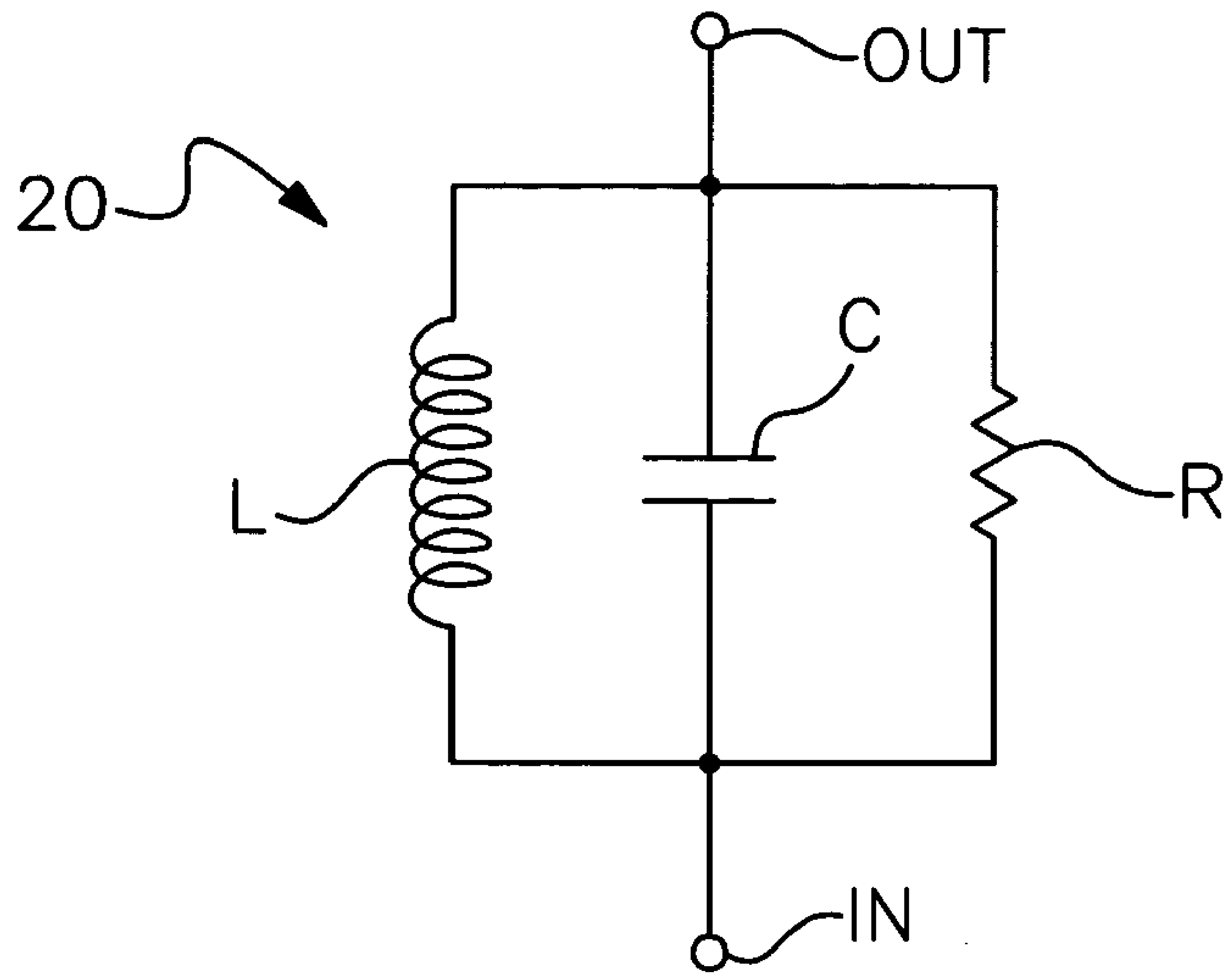


Fig. 1

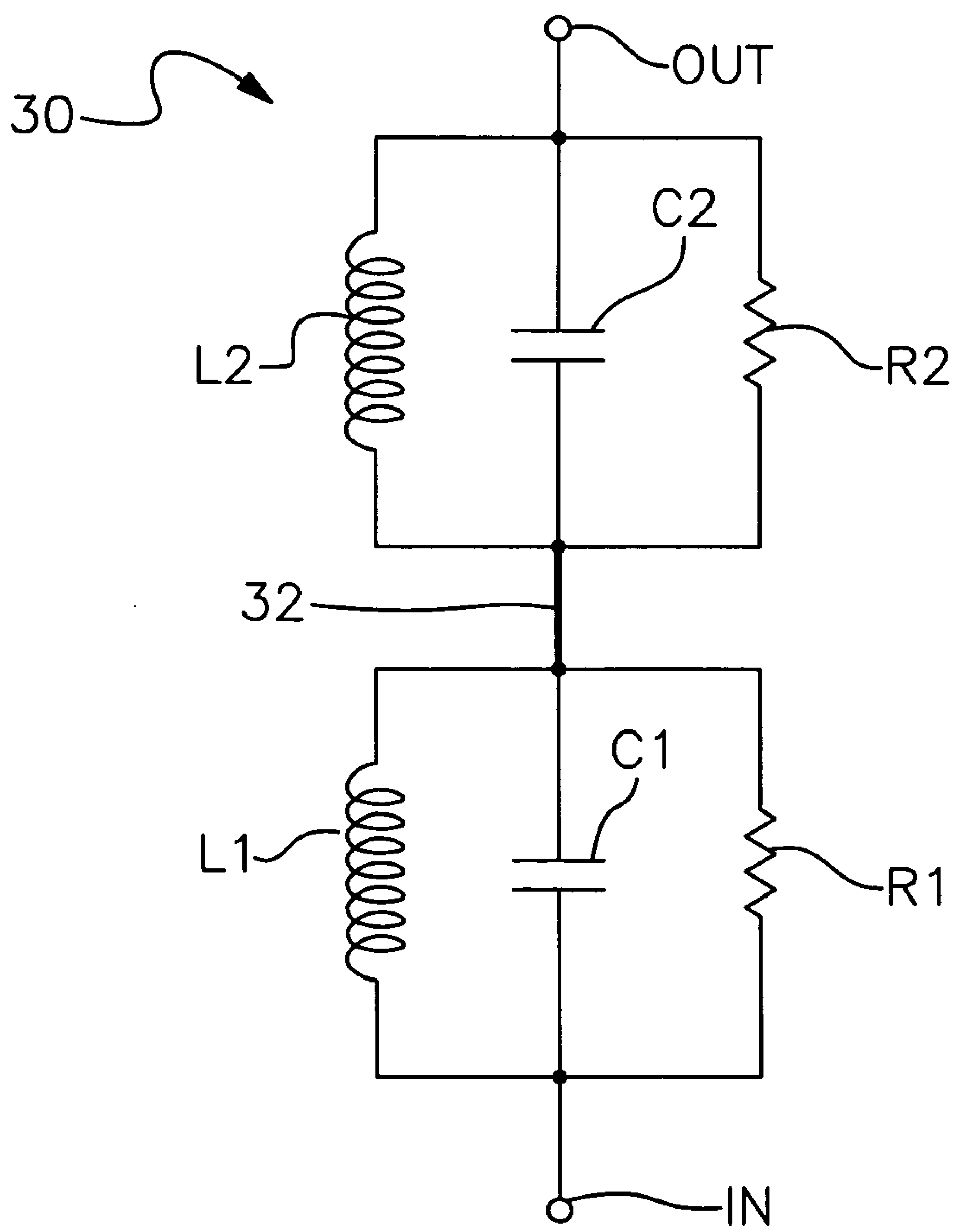


Fig. 2

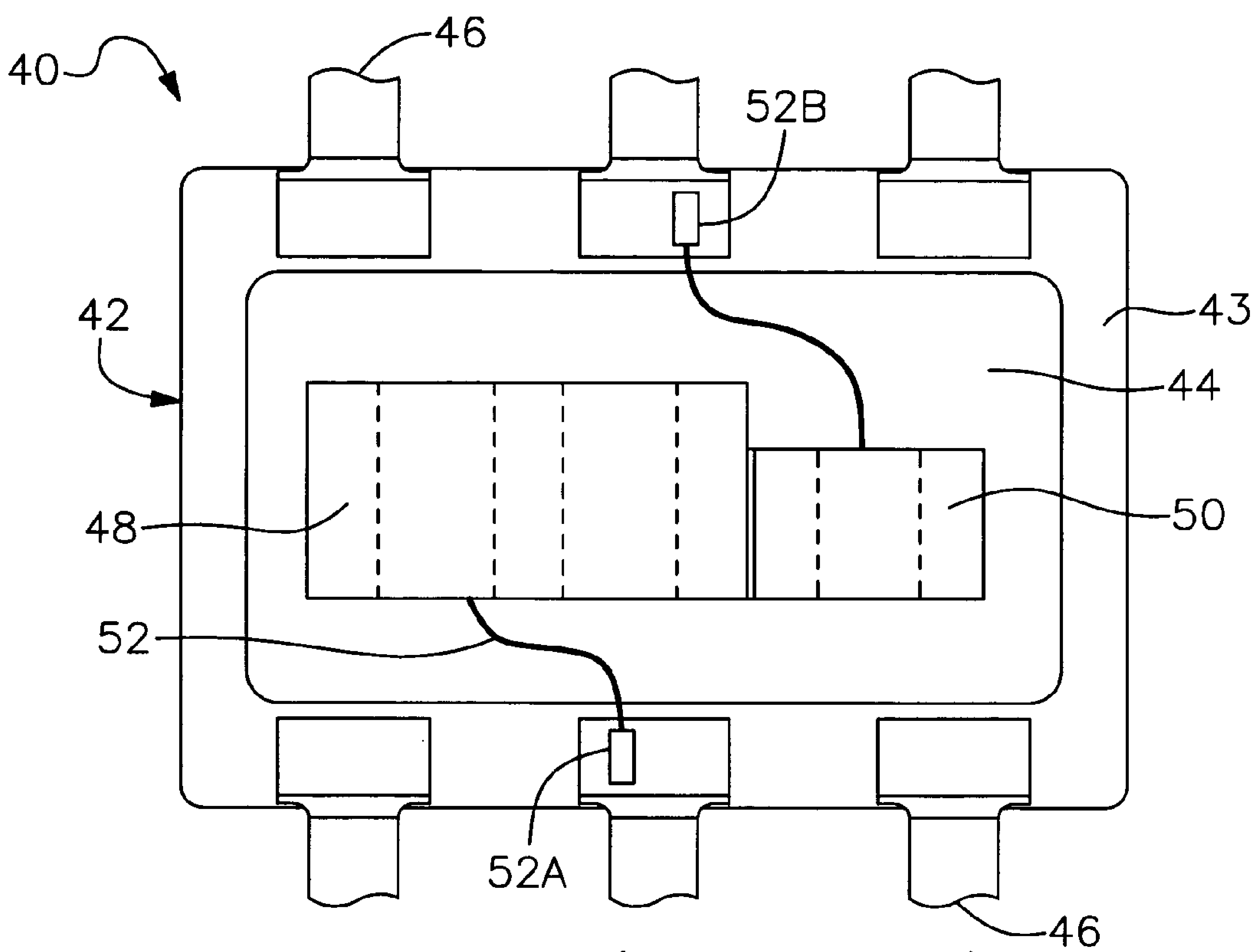


Fig. 3 (Prior Art)

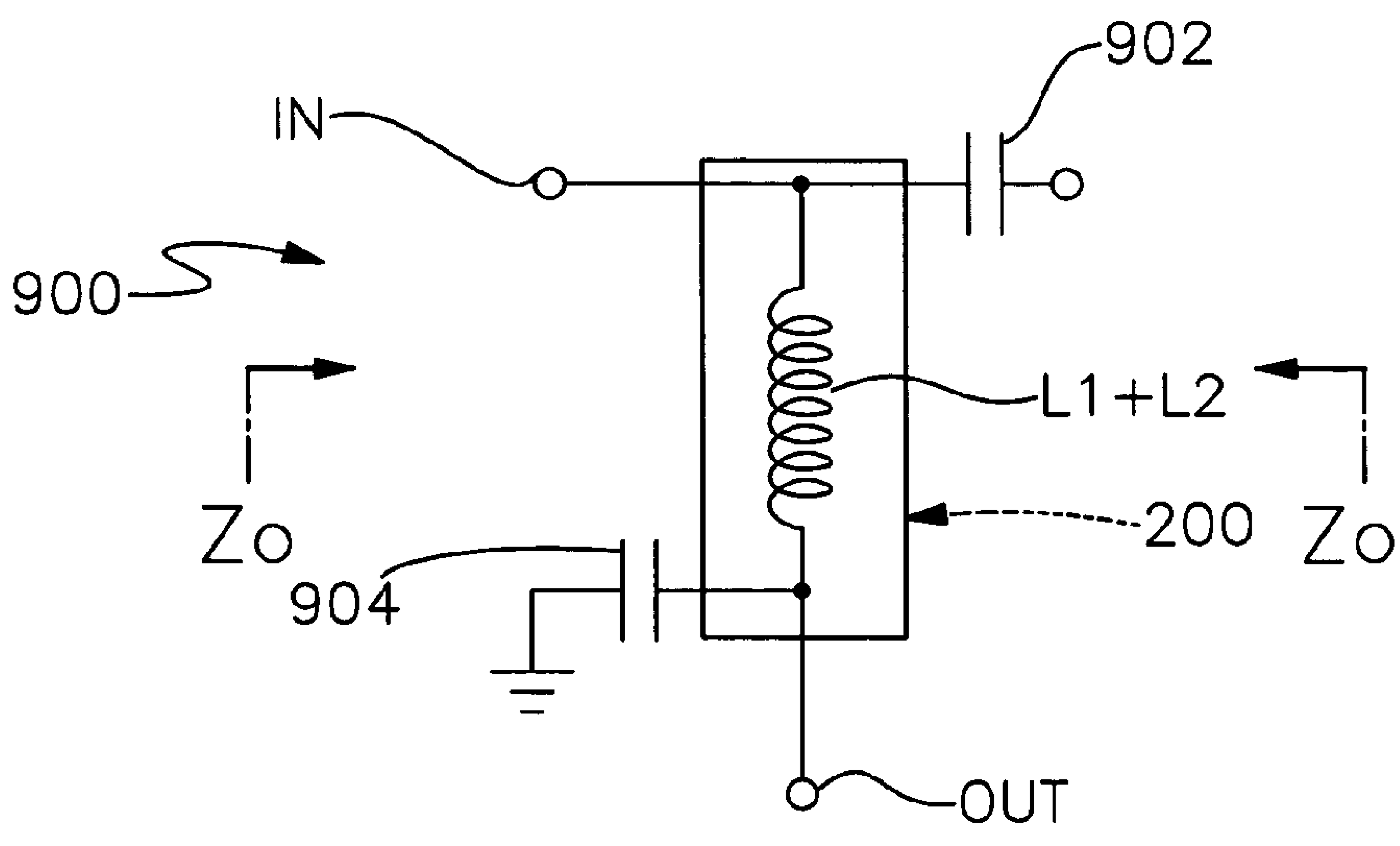
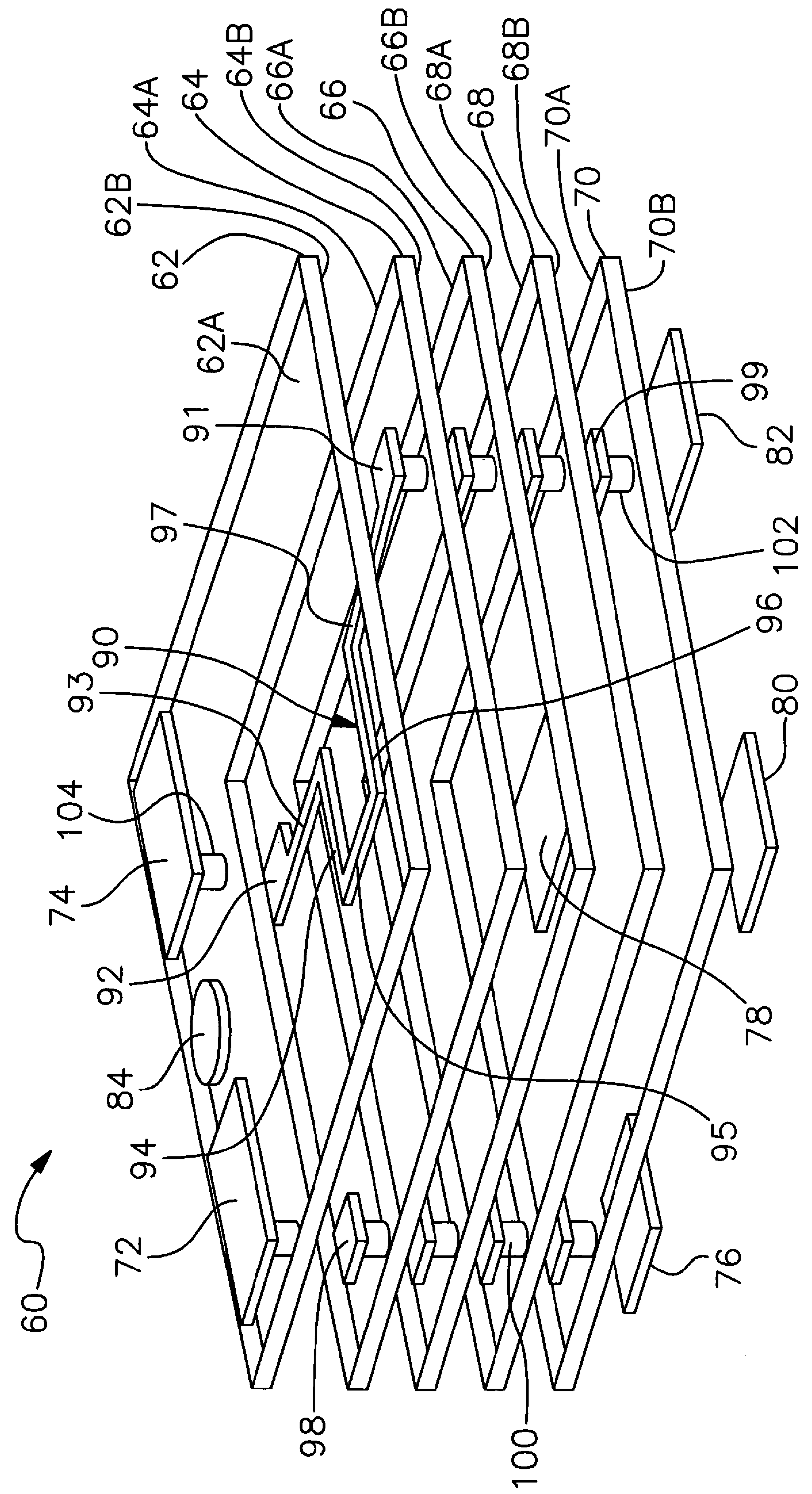


Fig. 9



60
62
62A
62B
64
64A
64B
66
66A
66B
68
68A
68B
70
70A
70B
72
74
76
78
80
82
84
90
91
92
93
94
95
96
97
98
99
100
102
104

Fig. 4

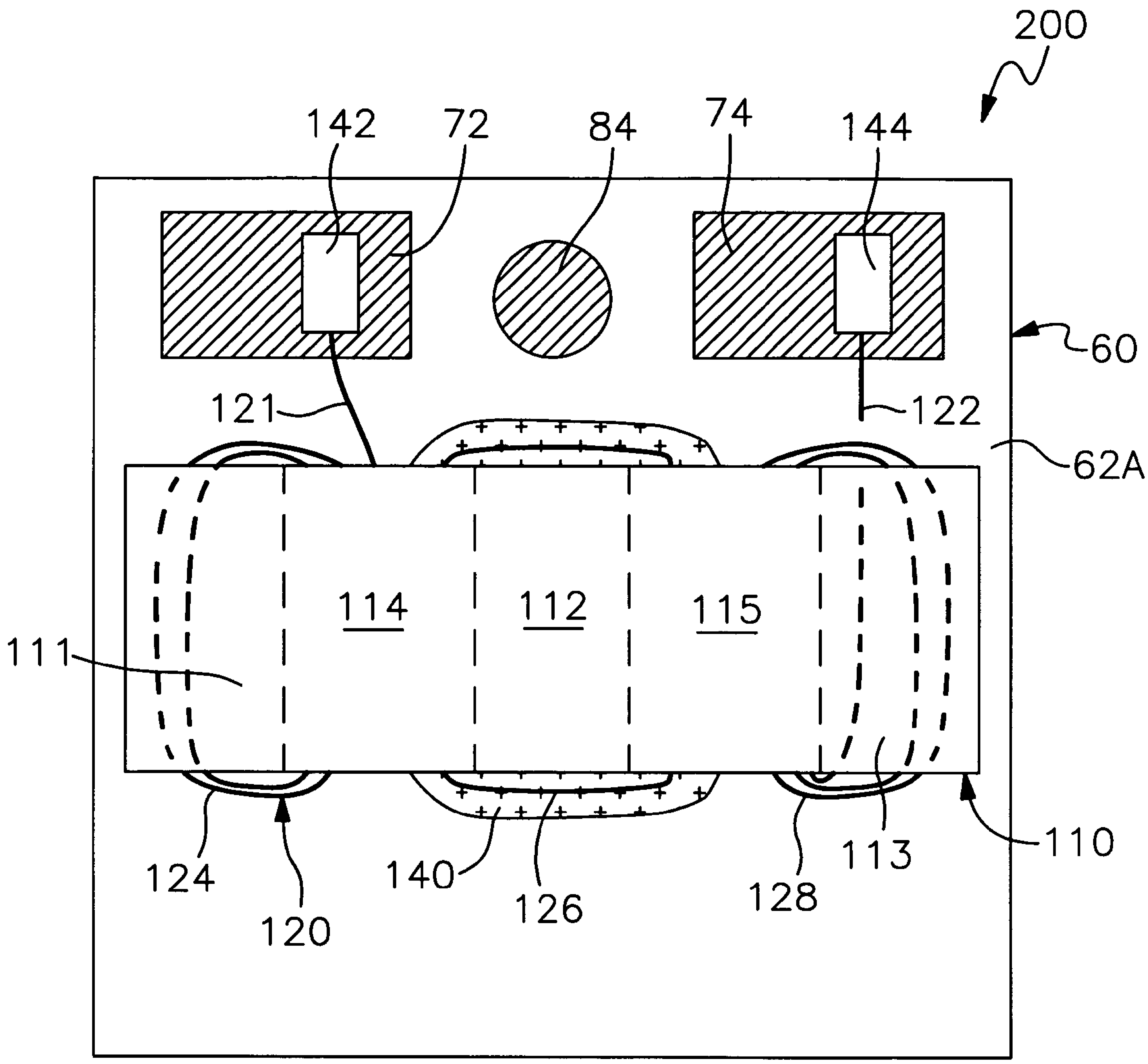

200
142
72
84
74
144
60
121
122
62A
111
114
112
115
124
120
140
126
128
113
110

Fig. 5

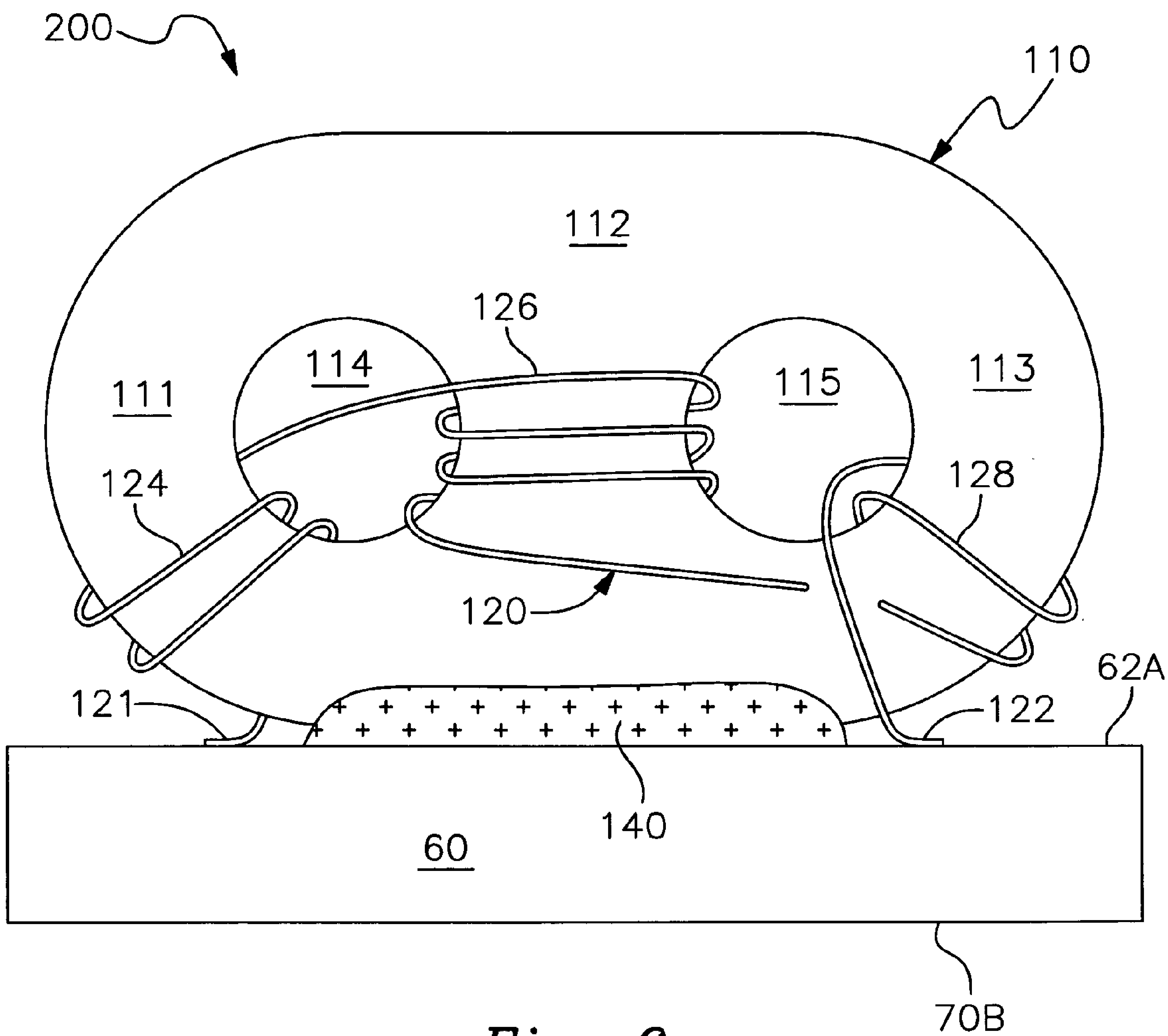
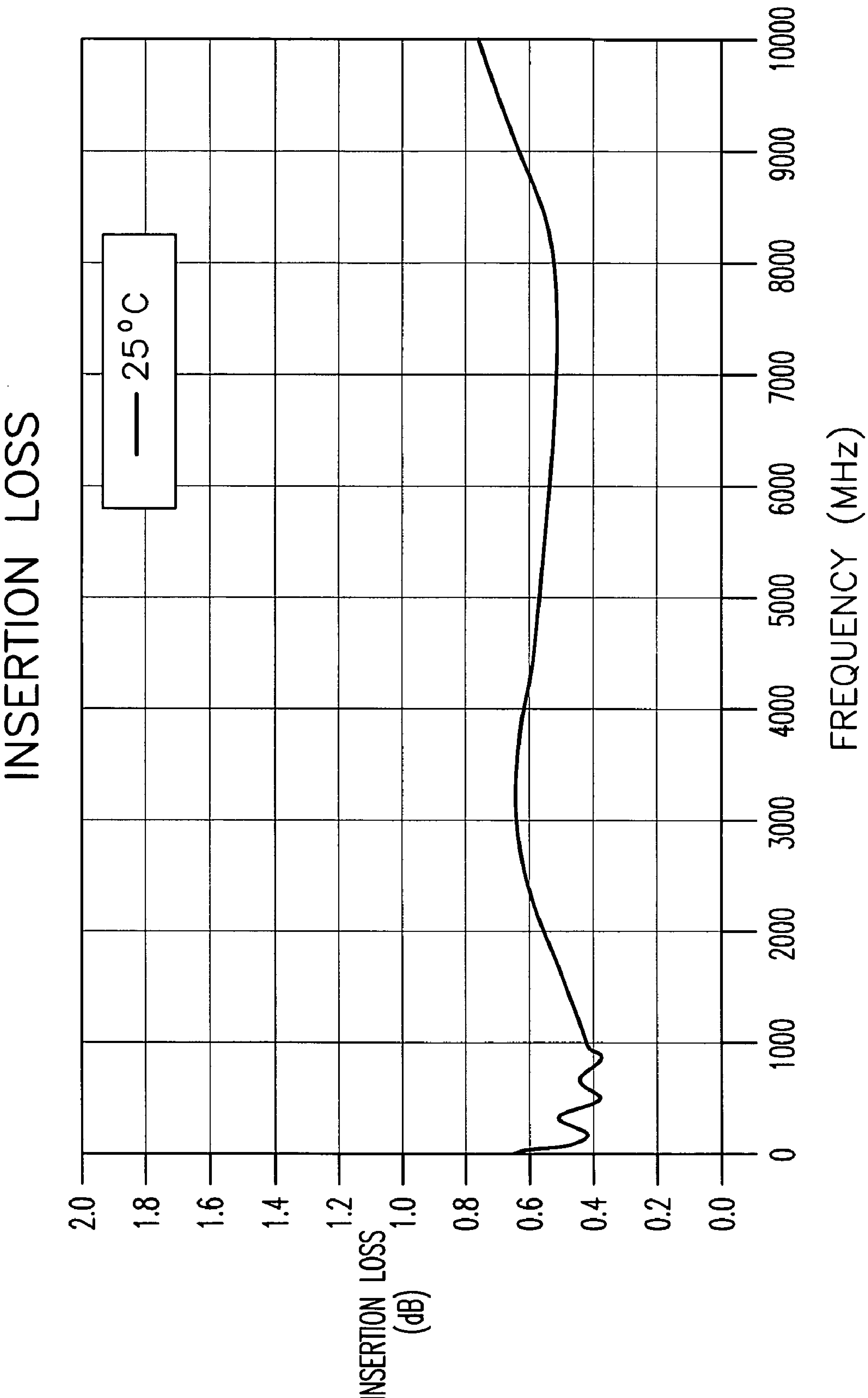

200
110
112
126
114
115
113
111
124
128
120
121
122
62A
140
60
70B

Fig. 6



INSERTION LOSS
25°C
INSERTION LOSS (dB)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
FREQUENCY (MHz)

Fig. 7

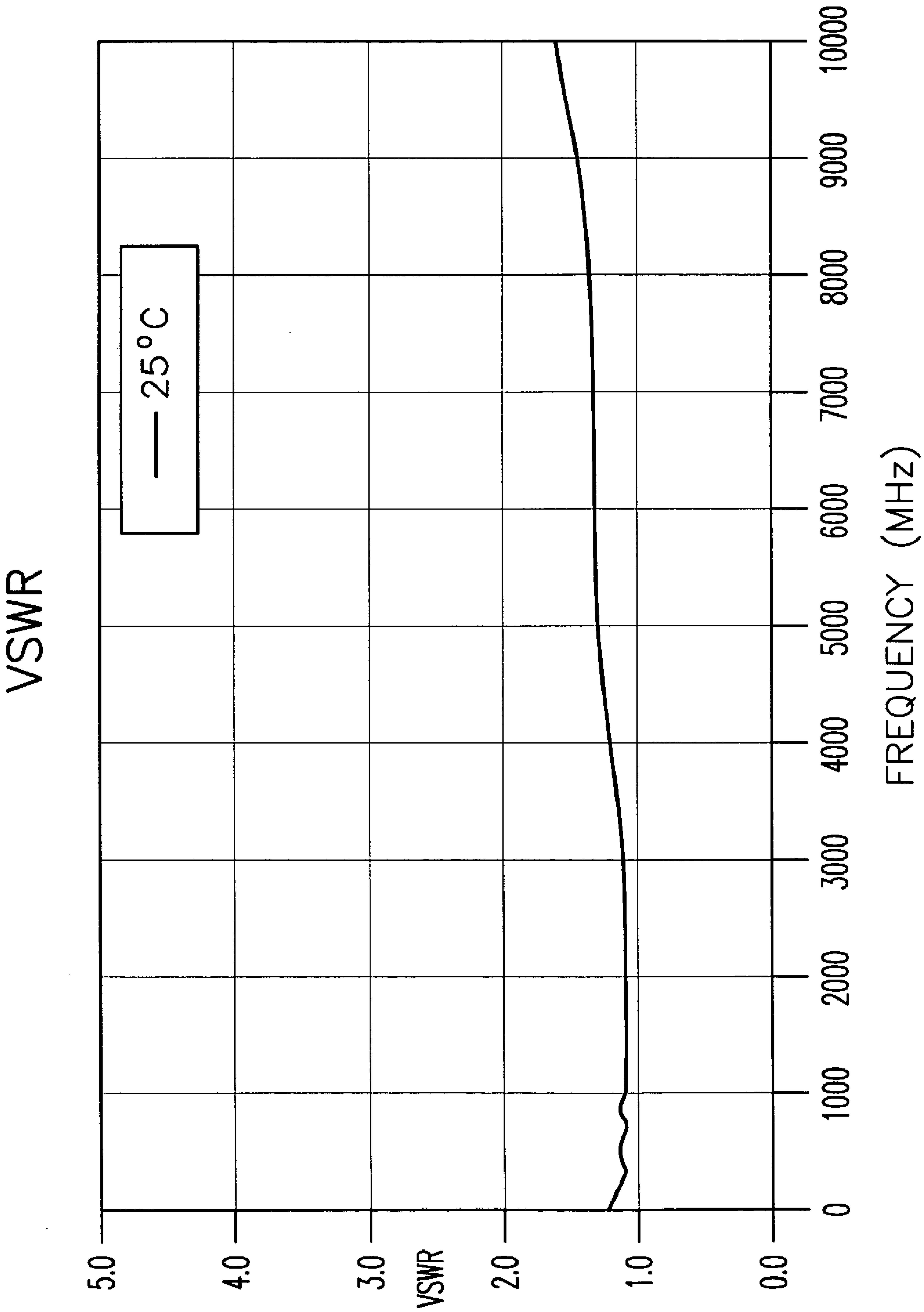

VSWR
— 25°C
5.0
4.0
3.0
VSWR
2.0
1.0
0.0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
FREQUENCY (MHz)

Fig. 8

MINIATURE WIDEBAND RF CHOKE

BACKGROUND

1. Field of the Invention

This invention relates to radio frequency (RF) chokes used with radio frequency and microwave frequency signals in general and more particularly to a miniature wideband RF choke that has a small package size and that can be manufactured at low cost.

2. Description of the Related Art

RF chokes are used in various devices. The RF choke separates an RF signal from a DC signal or a single-phase AC signal by presenting a low impedance to the DC or low frequency (60 Hz) AC signal. At the same time, the RF choke presents a high impedance to a RF signal, which typically has a frequency range of 5 to 1000 MHz. The DC or low frequency AC signal is shunted through the RF choke, while the RF signal is blocked. A perfect RF choke would pass all of the DC or low frequency AC signal through the RF choke while blocking all of the RF signal.

Referring to FIG. **1**, a schematic diagram of an RF choke **20** is shown. RF choke **20** has an input port IN and an output port OUT. Inductor L has one end connected to input port IN and another end connected to output port OUT. The inductor can be a wire wound on a ferrite core. The parasitic capacitance of the inductor is shown as capacitor C. The loss of the ferrite core and the resistance of the wire are shown as resistor R. For good performance at low frequencies, the inductance should be large. Unfortunately, when the inductance is large, the parasitic capacitance is also large and the parasitic resistance low. The result is that the electrical performance of the RF choke is poor at high frequencies.

In order to increase the bandwidth performance of RF choke **20** over a larger frequency range, a second inductor in series can be added. Referring to FIG. **2**, a schematic diagram of a wideband RF choke **30** is shown. Wideband RF choke **30** has an input port IN and an output port OUT. Inductor L1 has one end connected to input port IN and another end connected to node **32**. Inductor L2 has one end connected to output port OUT and another end connected to node **32**. The inductor L1 and L2 can be wires wound on ferrite cores. The parasitic capacitance of the inductors are shown as capacitors C1 and C2. The loss of the ferrite cores and the resistance of the wires are shown as resistors R1 and R2. Inductor L1 is selected to be large enough for proper low frequency operation. Inductor L2 is selected to be small for high frequency operation. Since inductor L2 has a small value, the parasitic capacitance C2 is small and the parasitic resistance R2 is high. Therefore RF choke **30** has good performance at both high and low frequencies.

Referring to FIG. **3**, a prior art RF choke assembly or package **40** is shown. RF choke assembly **40** has a plastic housing **42** with a top surface **43** and a cavity **44**. Six metal leads **46** are attached to top surface **43**. A ferrite binocular core **48** and a ferrite single core **50** are mounted in cavity **44**. Wire **52** has ends **52**A and **52**B. Wire **52** is wound on cores **48** and **50** and the ends attached to respective leads **46**. Core **48** forms inductor L1 and core **50** forms inductor L2. RF choke assembly **40** has typical dimensions of 0.310 inches in length by 0.280 inches in width by 0.112 inches in height. RF choke **40** has an area of 0.0868 square inches. RF choke assembly or package **40** is typically soldered onto another printed circuit board.

Unfortunately, RF choke assembly or package **40** takes up excessive space when it is mounted on a printed circuit board. The mounting of the cores side by side results in a large package. The mounting of the cores and winding of the wire are manual operations that are difficult to automate. It is desirable, in order to reduce cost, to automate as much of the assembly process as possible.

While RF chokes have been used, they have suffered from being too large, expensive, difficult to assemble and not easily manufactured using automated equipment. A current unmet need exists for a wideband RF choke that has a smaller size, can be assembled at a low cost and that can be manufactured using automated equipment.

SUMMARY

It is a feature of the invention to provide a miniature wideband RF choke that has a small package size and that can be manufactured at low cost.

A further feature of the invention is to provide a radio frequency choke that includes a substrate having a top surface and a bottom surface. A first inductor is located within the substrate. The first inductor has a first and second end. A first and second top terminal are located on the top surface. A first and second bottom terminal are located on the bottom surface. A first via extends through the substrate between the first top terminal and the first bottom terminal. A second via extends through the substrate between the second top terminal and the first end of the first inductor. A third via extends through the substrate between the second bottom terminal and the second end of the first inductor. A second inductor is attached to the top surface. The second inductor has a core and a wire wound on the core. The wire has a first end connected to the first top terminal and a second end connected to the second top terminal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an electrical schematic diagram of an RF Choke.

FIG. **2** is an electrical schematic diagram of a wideband RF Choke.

FIG. **3** is a top view of a prior art RF choke package.

FIG. **4** is an exploded view of the substrate of the present invention.

FIG. **5** is a top view of a miniature wideband RF choke in accordance with the present invention.

FIG. **6** is a side view of FIG. **5**.

FIG. **7** is a graph showing insertion loss versus frequency for the RF choke of FIG. **5**.

FIG. **8** is a graph showing VSWR versus frequency for the RF choke of FIG. **5**.

FIG. **9** is an electrical schematic diagram of a test circuit for an RF choke.

It is noted that the drawings of the invention are not to scale.

DETAILED DESCRIPTION

Referring to FIG. **4**, an exploded view of a low temperature co-fired ceramic (LTCC) substrate **60** is shown. Substrate **60** has a top surface **62**A and a bottom surface **70**B. LTCC substrate **60** is comprised of multiple layers of low temperature co-fired ceramic material, Planar layers **62**, **64**, **66**, **68** and **70** are all stacked on top of each other and form a unitary structure **60** after firing in an oven. LTCC layers **62–70** are commercially available in the form of a green unfired tape from Dupont Corporation. Each of the layers has a top surface, **62**A, **64**A, **66**A, **68**A and **70**A. Similarly, each of the layers has a bottom surface, **62**B, **64**B, **66**B, **68**B and **70**B.

The layers have several circuit features that are patterned on the surfaces. Layer **62** has several circuit features that are patterned on surface **62**A. Surface **62**A has two terminals **72** and **74** and an orientation mark **84**. The terminals are electrically connected to vias. Terminal **72** is connected to via **100** and terminal **74** is connected to via **104**. The vias extend through some of the layers. The vias are formed from an electrically conductive material and electrically connect one layer to another layer.

Layer **64** has a conductor line **90** located on surface **64**A. Conductor line **90** has a wide end **91**, another wide end **92** and thin joined segments **93**, **94**, **95**, **96** and **97**. Conductor line **90** is U-shaped. Wide end **91** is connected to via **102**. Wide end **92** is connected to via **104**. Conductor line **90** has an associated inductance and forms inductor L**2** in the electrical schematic of FIG. **2**. Conductor line **90** is therefore sandwiched between layers **62** and **64**. Conductor line **90** can have typical dimensions of 0.16 inches in length, 0.004 inches in width and 0.0005 inches in thickness.

A via pad **98** is located on surfaces **64**A, **66**A, **68**A and **70**A. Via pad **98** is connected to via **100** and helps to make a more reliable electrical connection between the layers. Similarly, via pads **99** are connected to via **102**.

Layer **70** has several circuit features that are patterned on surface **70**B. Surface **70**B has four terminals **76**, **78**, **80** and **82**. Terminal **76** is connected to via **100** and terminal **82** is connected to via **102**.

The circuit features and vias of substrate **60** are formed by screen printing conventional thick film conductor and via materials on the low temperature ceramic layers. The layers are then stacked onto each other and fired in an oven to produce a unitary part.

Referring to FIGS. **5** and **6**, the electrical schematic of the wideband RF choke of FIG. **2** is realized in a physical package. Miniature wideband RF choke or choke assembly **200** has a binocular core **110** mounted to top surface **62**A. Core **110** is mounted to surface **62**A by an adhesive **140**. Adhesive **140** can be an epoxy or other suitable glue. Core **110** is a ferrite binocular core with three legs **111**, **112** and **113**. Leg **112** is the center leg. Core **110** has apertures **114** and **115**.

A wire **120** is wound on core **110**. Wire **120** has ends **121** and **122**. Wire **120** is wound for 2 turns on leg **111** to form a winding **124**. Wire **120** is wound for 3 turns on center leg **112** to form a winding **126**. Wire **120** is wound for 2 turns on leg **113** to form a winding **128**. The wire ends are attached to terminals **72** and **74** by welds. Wire end **121** is attached to terminal **72** by weld **142**. Wire end **122** is attached to terminal **74** by weld **144**. Wire **120** can be 36-gauge magnet wire.

Core **110** and wire **120** has an associated inductance and forms inductor L**1** of the electrical schematic of FIG. **2**.

RF choke **200** has an overall size of 0.15 inches in length, 0.15 inches in width and 0.15 inches in height. RF choke **200** can be smaller than these dimensions. RF choke **200** has an area of 0.0225 square inches.

RF choke **200** would typically be mounted to a printed circuit board (not shown). The terminals **76**, **78**, **80** and **82** would be attached to the printed circuit board using a reflowed solder paste. Solder paste would be screen printed onto the printed circuit board. Terminals **76**, **78**, **80** and **82** would be placed onto the solder paste and melted in a re-flow oven to attach the RF choke to the printed circuit board.

RF choke **200** can be assembled in the following manner:

1. Core **110** is wound with wire **120** to form inductor L**1**.
2. Adhesive **140** is dispensed onto top surface **62**A.
3. Core **110** with windings is placed onto adhesive **140** and cured.
4. Wire ends **121** and **122** are welded to terminals **72** and **74**.
5. The completed assembly is electrically tested.

The present invention has several advantages. Since, inductor L**2** or conductor line **90** is integrated into the low temperature co-fired ceramic substrate, it is not mounted separately adjacent to inductor L**1** or core **110**. This creates a smaller overall package size.

The use of the integrated inductor reduces the number of assembly steps for the RF choke resulting a lower cost of assembly.

By placing inductor L**2** within substrate **60**, the remaining manufacturing steps can be done using automated equipment. Automated assembly reduces the cost of manufacturing.

Fabricating the RF choke using a low temperature co-fired ceramic substrate results in more uniform electrical characteristics.

A RF choke in accordance with the present invention was built and tested for electrical performance. Inductor L**1** had an inductance value of 4 micro-henries at 0 milli-amps of current and 0.95 micro-henries at 100 milli-amps (DC) of current. Inductor L**2** had an inductance value of 6 nano-henries.

FIG. **9** shows an electrical schematic diagram of a test circuit **900** that was used to test RF choke **200**. Test circuit **900** has RF choke **200** connected with a pair of capacitors **902** and **904**. Capacitor **902** is connected between the input port IN and a RF output port RF out. Capacitor **904** is connected between the output port OUT and ground.

Referring to FIG. **7**, a graph showing the insertion loss for wideband RF choke **200** is shown over the frequency range of from 30 to 10,000 MHz. The insertion loss was typically 0.5 dB with a maximum of 1.1 dB. FIG. **8** shows a graph of VSWR versus frequency for wideband RF choke **200**. The VSWR was typically 1.1 with a maximum of 1.6.

While the invention has been taught with specific reference to these embodiments, someone skilled in the art will recognize that changes can be made in form and detail without departing from the spirit and the scope of the invention. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the description. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed is:

1. An RF choke comprising:

a) a substrate having a top layer, a bottom layer, and a plurality of inner layers;

b) a conductor line formed on an inner layer, the conductor line having a first and second end;

c) first terminal and second terminal located on the top layer;

d) third terminal and fourth terminal located on the bottom layer;

e) a first via extending through the substrate between the first terminal and the third terminal;

f) a second via extending through the substrate between the second terminal and the first end of the conductor line;

g) a third via extending through the substrate between the fourth terminal and the second end of the conductor line;

h) a core attached to the top layer; and

i) a wire having a first end and a second end, the wire wound on the core, the first end connected to the first terminal and the second end connected to the second terminal.

2. The RF choke according to claim **1**, wherein the substrate is formed from layers of low temperature co-fired ceramic.

3. The RF choke according to claim **1**, wherein the third terminal forms an input port and the fourth terminal forms an output port.

4. The RF choke according to claim **1**, wherein the core is a binocular core.

5. The RF choke according to claim **1** wherein the core is attached to the top layer by an adhesive.

6. The RF choke according to claim **1** wherein the core has a first leg, a second leg and a third leg.

7. The RF choke according to claim **6** wherein the wire is wound on the first leg for 2 turns, on the second leg for 3 turns and on the third leg for 2 turns.

8. The RF choke according to claim **6** wherein the core and wire forms a first inductor and the conductor line forms a second inductor, the first and second inductors being series connected.

9. A radio frequency choke comprising:

a) a substrate having a top surface and a bottom surface;

b) a first inductor located within the substrate, the inductor having a first and second end;

c) first top terminal and second top terminal located on the top surface;

d) first bottom terminal and second bottom terminal located on the bottom surface;

e) a first via extending through the substrate between the first top terminal and the first bottom terminal;

f) a second via extending through the substrate between the second top terminal and the first end of the inductor;

g) a third via extending through the substrate between the second bottom terminal and the second end of the inductor; and

h) a second inductor attached to the top surface, the second inductor having a core and a wire wound on the core, the wire having a first end connected to the first top terminal and a second end connected to the second top terminal.

10. The choke according to claim **9** wherein the core is attached to the top surface by an adhesive.

11. The choke according to claim **9**, wherein the first bottom terminal forms an input port and the second bottom terminal forms an output port.

12. The choke according to claim **9**, wherein the core is a binocular core.

13. The choke according to claim **12** wherein the binocular core has a first leg, a second leg, a third leg and two apertures.

14. The choke according to claim **13** wherein the wire is wound on the first leg for 2 turns, on the second leg for 3 turns and on the third leg for 2 turns.

15. The choke according to claim **9** wherein the choke is less than 0.150 inches in length by 0.150 inches in width by 0.150 inches in height.

16. The choke according to claim **9** wherein the first inductor is formed by a conductor line located within the substrate.

17. A choke comprising:

a) a low temperature co-fired ceramic substrate having a first, second, third, fourth and fifth layer;

b) first terminal and second terminal located on the first layer;

c) third terminal and fourth terminal located on the fifth layer;

d) a first inductor attached to the first layer, the first inductor having a core and a wire wound on the core, the wire having one end attached to the first terminal and the other end attached to the second terminal;

e) a second inductor located on the second layer, the second inductor having a conductor line, the conductor line having one end attached to the second terminal and another end attached to the fourth terminal;

f) a first via extending through the substrate between the first terminal and the third terminal;

g) a second via extending through the substrate between the second terminal and the conductor line; and

h) a third via extending through the substrate between the fourth terminal and the conductor line.

18. The choke according to claim **17**, wherein the third terminal forms an input port and the fourth terminal forms an output port.

19. The choke according to claim **17**, wherein the core is a binocular core.

20. The choke according to claim **19** wherein the binocular core has a first leg, a second leg, a third leg and two apertures.

21. The choke according to claim **20** wherein the wire is wound on the first leg for 2 turns, on the second leg for 3 turns and on the third leg for 2 turns.

22. The choke according to claim **17** wherein the choke is less than 0.150 inches in length by 0.150 inches in width by 0.150 inches in height.

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